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ADMINISTRATIVE REPORT

Proceedings of The Thirty-Seventh Annual Tuna Conference

May 18-21, 1986

Edited by Richard W. Brill

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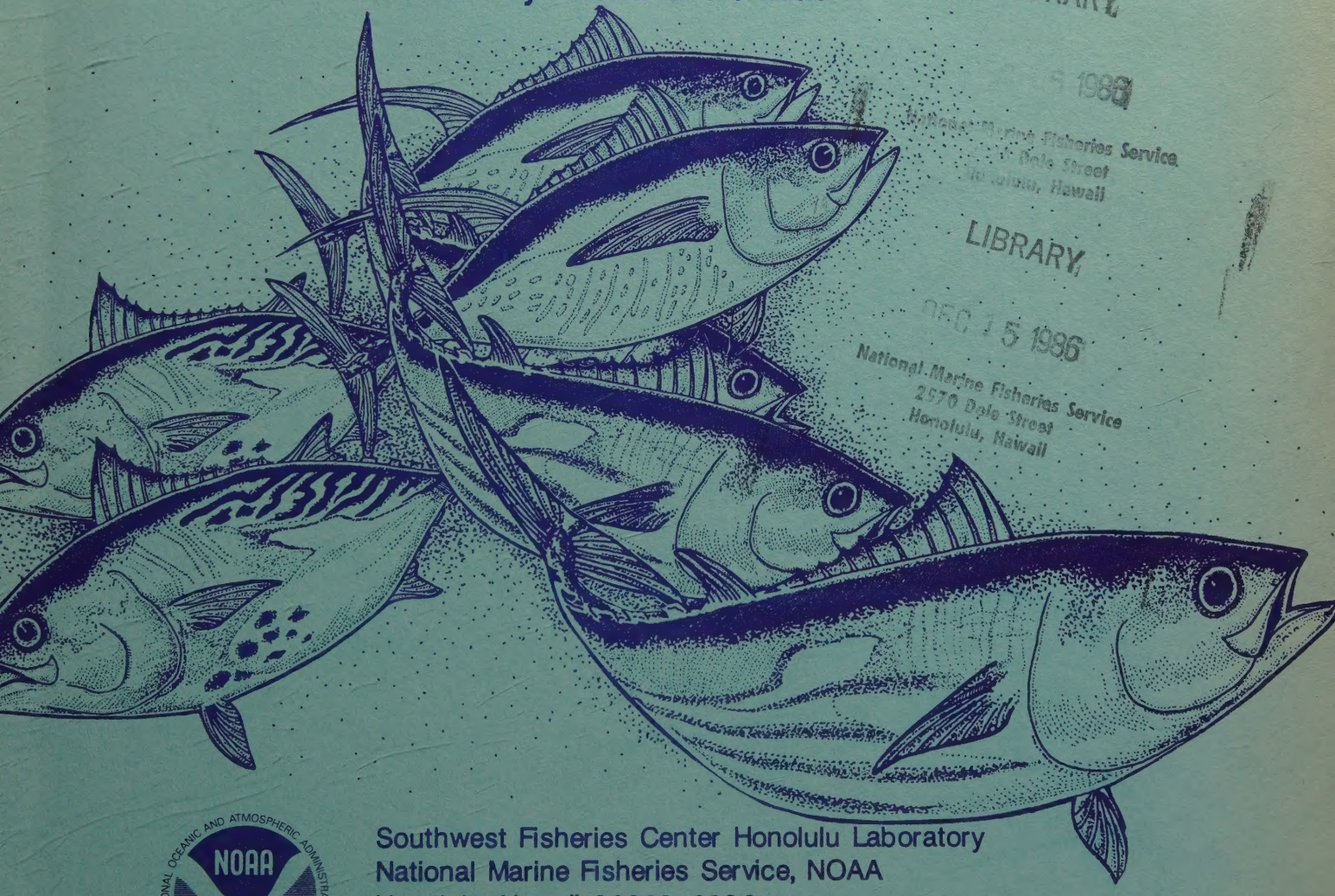

Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

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PROCEEDINGS OF THE 37TH ANNUAL TUNA CONFERENCE

MAY 18-21, 1986

Edited by

Richard W. Brill
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

November 1986

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PROCEEDINGS OF THE 37TH ANNUAL TUNA CONFERENCE

University of California Conference Center
Lake Arrowhead, California
May 18-21, 1986

Richard W. Brill, Chairman
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
2570 Dole Street, Honolulu, Hawaii 96822-2396

PREFACE

The 37th Annual Tuna Conference was held again this year at the University of California Conference Center, Lake Arrowhead California, 18-21 May 1986. The Tuna Conference has been an annual event since 1950, providing an opportunity for scientists, fishery managers, government officials, and industry representatives to meet, exchange information, and discuss research on tuna and tunalike species. As in the past, this year's meeting was sponsored by the National Marine Fisheries Service and the Inter-American Tropical Tuna Commission. Sixty-five people attended the conference and 31 oral presentations were delivered. Abstracts of the oral presentations are included in these proceedings.

Effective fisheries management requires the successful integration of population biology information, appropriate computer models, economics studies, oceanographic information, and physiological-behavioral research. It was the objective of this year's conference to bring together experts in all these fields and industry representatives to explore recent changes in the tuna industry and recent developments in tuna research, with special emphasis on improving science-industry-government cooperation.

On a personal note, I would like to express my sincere appreciation to the participants and speakers at this year's conference. If the 1986 Tuna Conference is considered successful it was because of their efforts not mine.

Witold Klawe, Inter-American Tropical Tuna Commission, was elected Chairman of the 38th Tuna Conference to be held again at the University of California Conference Center.

Richard W. Brill
Chairman, 37th Annual Tuna Conference

AGENDA

37th ANNUAL TUNA CONFERENCE
LAKE ARROWHEAD, CALIFORNIA

Sunday, 18 May 1986

1530-1830 Registration

1830 Dinner

1930 Reception

Monday, 19 May 1986

0700-0800 Registration

0900-0915 Welcome and Introduction to the 37th Annual Tuna Conference
Richard W. Brill, NMFS (Conference Chairman)

SESSION I. FISHERY MANAGEMENT
Norman Bartoo, Convener

0915-0945 Tuna and Related Research in the National Marine Fisheries Service
Izadore Barrett, NMFS

0945-1015 Important Recent Changes in the U.S. Tuna Industry and Government Policies From Industry's Perspective
August Felando, American Tuna Boat Association

1015-1030 BREAK

1030-1100 Recent Changes in Tuna Research Requirements
Robert E. Kearney, IATTC

SESSION II. FISHERY ECONOMICS
Alvin Z. Katekaru, Convener

1100-1130 Recent Problems in the U.S. Tuna Industry and an Outlook
Dennis M. King, E.R.G. Pacific Inc.

1130-1200 Licensing Distant-Water Tuna Fishing Fleets: The Experience of Papua New Guinea
David J. Doulman, East-West Center

1200-1300 LUNCH

SESSION III. FISHERY BIOLOGY
William H. Bayliff, Convener

1300-1330 Current Situation Regarding Tuna Fishing in the Eastern Pacific
James Joseph, IATTC (Cancelled)

1330-1400 Status of Yellowfin Tuna Fishery in the Gulf of Mexico
Guillermo Compean Jimenez, Universidad Automa de Neuvo Leon

1400-1415 BREAK

1415-1445 Recent Developments in Tuna Fishing in the Indian Ocean
Richard S. Shomura, NMFS

1445-1515 U.S. Exploratory Fishing for Albacore in the South Pacific
R. Michael Laurs, NMFS

1515-1545 Coherent Theory on Tuna Behavior
Michel Petit, ORSTOM

1545-1600 BREAK

SESSION IV. COMPUTERS AND MATHEMATICAL MODELING
Ramon Conser, Convener

1600-1630 Methodological Considerations for the Abundance Estimation of Dolphin Populations Using Observer Data
Alejandro A. Anganuzzi and Stephen T. Buckland, IATTC

1630-1700 Movement Analysis of Skipjack Tuna Tags
Raymond Hilborn, South Pacific Commission

1700-1730 *Gill Ventilation and Perfusion in Free Swimming Tuna
David R. Jones, University of British Columbia

1730-1830 SUSHI HOUR (compliments of U.S. Tuna Foundation)

1830 DINNER

*Scheduled at this time at presenter's request.

Tuesday, 20 May 1986

SESSION IV. (Continued)

0900–0930 Analyzing Tag Returns From a Localized Fishery Harvesting A Widely Distributed, Dispersive Fish Population
Pierre Kleiber, NMFS

0930–1015 *Forecasting Albacore Catches: Some Preliminary Results
Roy Mendelssohn and David Husby, PFEG

1015–1030 BREAK

SESSION V. OCEANOGRAPHY
Richard W. Brill, Convener

1030–1100 Satellite Remote Sensing and Tuna Fisheries
R. Michael Laurs, NMFS

1100–1130 Fronts and Tuna Aggregations
Mitchell Roffer, University of Miami (Cancelled)

1130–1200 Possible Relationship Between El Niño and Japanese Longline Fishing
Ziro Suzuki, Far Seas Research Laboratory, Japan

1200–1300 LUNCH

1300–1330 Are El Niño Conditions Returning to the Eastern Tropical Pacific?
Forrest R. Miller, IATTC

1330–1400 Horizontal and Vertical Movement Patterns of FAD-Associated Yellowfin Tuna
Kim N. Holland, Hawaii Institute of Marine Biology

SESSION VI. PHYSIOLOGY
E. Don Stevens, Convener

1400–1430 Cardiovascular and Respiratory Responses of Skipjack and Yellowfin Tunas Exposed to Brief Periods of Low Ambient Oxygen
Peter G. Bushnell, University of Hawaii

1430–1445 BREAK

*Extra time scheduled at presenter's request.

1445-1515 Oxygen-Sensitive Afferent Information Arising from the First Gill Arch of Yellowfin Tuna
William K. Milsom, University of British Columbia

1515-1545 A New Analysis of the Tuna Burn Problem
Peter W. Hochachka, University of British Columbia

1545-1615 Skipjack Tuna as an Elite Athlete of the Sea: Insights from Lactate Metabolism
Jean-Michel Weber, University of British Columbia

1615-1630 BREAK

1630-1700 Strategies for Elevating Brain and Eye Temperatures in Tunas, Sharks, and Billfishes
Barbara A. Block, Duke University

SESSION VII. TUNA BIOLOGY
David B. Holts, Convener

1700-1730 Revision of the Frigate Tunas, Genus Auxis
Bruce B. Collette, NMFS

1730-1800 The Standard Metabolic Rate of Tunas: Why Is It So High?
Richard W. Brill, NMFS

1830 DINNER

Wednesday, 21 May 1986

SESSION VII. (Continued)

0900-0930 Natural Mortality and Its Role in Population Estimation
Earl Weber, NMFS

0930-1000 Life and Death on the High Seas: Reflections on Connections Between Natural Mortality and Physiological Condition
Elizabeth Vetter, NMFS

1000-1030 Condition and Performance: Factors Affecting Susceptibility of Tuna to Predation
Christofer H. Boggs, NMFS

1030-1040 BREAK

1040-1110 Effect of a Cestode (Tapeworm) Pleuroceroid Parasite Infesting the Dorsal Aorta of the Yellowfin Tuna, Thunnus albacares
Robert E. Bourke, NMFS

1110–1140	Growth of Yellowfin Tuna, Thunnus albacares, in the Eastern Pacific Ocean Based on Otolith Increments Alex Wild, IATTC
1140–1210	Geographic Variation of Reproductive Characteristics in Black Skipjack Tuna, Euthynnus lineatus. Kurt M. Schaefer, IATTC
1210–1300	LUNCH AND BUSINESS MEETING
1300	ADJOURN

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Introduction and Welcome to the 37th Annual Tuna Conference

Richard W. Brill, Chairman 37th Annual Tuna Conference
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

This year's conference stresses recent changes in the tuna fishing industry and recent developments in tuna research. These changes and developments are to be discussed from the perspectives of research scientists, fishery managers, government officials, and industry representatives.

In an unmanaged fishery, fishing effort is generally controlled by economic and political forces. Unfortunately, this has been shown time and time again to be the formula for disaster. In unregulated fisheries, fishing effort usually expands rapidly. Increasing amounts of capital tend to be invested, until there is so much capital (i.e., fishing effort) that no one can make a decent return on their investment. There just is not enough biological production to provide adequate returns on so much capital. Fishing effort is eventually reduced as capital is transferred or is simply lost. This is a situation that is well avoided.

Fisheries need management. However, for fishery management to be truly effective, knowledge on how many fish can be caught on a sustained basis is required. In other words information on how much capital an exploited population can support must be known. Population biology information (i.e., stock assessment) is traditionally based on catch and effort data analyzed with appropriate computer models. This information is then passed to fishery managers who determine fishery regulations.

However, in many fisheries catch and effort data are now known not to be enough. Catch and effort data are gathered "after the fact," which in many cases is after a fishery is already overcapitalized. Furthermore, fish populations are known to change cyclically and independently of changes in fishing effort, as the recent El Niño event has clearly shown. Therefore, I argue that truly effective fisheries management requires not only a constant infusion of oceanographic information, but also biological, physiological, and behavioral information on the exploited species. Furthermore, if physiological research is combined with oceanographic research, predicting species movements, changes in abundance, and gear vulnerability is possible.

Current population dynamics models often still require unrealistic biological assumptions such as: that fish and fishing effort are randomly distributed relative to one another, that gear catches all sizes of fish equally well, or that gear is equally effective under different oceanographic conditions. Since none of these assumptions are usually met, I argue truly effective fisheries management requires a balanced approach. In other words, input from industry, economists, fishery biologists, mathematical modelers, oceanographers, and physiologists are all required. The

cost of having this many people working on one fishery is expensive and is obviously not justified for relatively small fisheries. However, the worldwide tuna catch is estimated to be worth approximately $3 billion per year and the U.S. tuna industry is the largest fishing industry in terms of tonnage and the second largest in terms of revenue of any U.S. fishing industry. Therefore if any fishery is justified in having a complete management structure, it is the tuna fishery.

Unfortunately, with respect to tuna fisheries management, the oceanographers, fishery biologists, physiologists, fishery managers, economists etc. are, like the tunas themselves, scattered widely. People involved with tuna research and management are often located in different countries, in different agencies within the same country, or in different laboratories within the same governmental agency. Effective communication, which is the lifeblood of effective management, can therefore sometimes be difficult.

Much of the traditional catch and effort data used for tuna stock assessments are becoming unavailable. Yet, fair management decisions and equitable resource allocations are pressing problems. Maximally effective use of all the people involved in fisheries management and tuna research are now more important than ever. It is one of the primary objectives of this year's Tuna Conference to bring together all the players in this game and to talk about how our efforts could be more effectively integrated.

Let us begin.

TUNA AND RELATED RESEARCH IN THE NATIONAL MARINE FISHERIES SERVICE

Izadore Barrett
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
La Jolla, California 92038

The tuna world we have known in past years is in a state of flux with traditional bonds and arrangements changing rapidly. Although the United States is a major component in the international tuna business the domestic industry is faced with the challenge of expanding foreign fleets, high operating costs which have led to the closing of all but one major cannery in the continental United States, an influx of canned tuna imports, and a dwindling fleet of tropical tuna seiners.

In the face of this new reality, the United States, and by inference the National Marine Fisheries Service (NMFS), has the objective to provide a continuing supply of tuna to American consumers by maintaining world stocks of tunas at maximum sustainable yield and by ensuring the United States access to these stocks. With this purpose foremost, the role of the Federal Government is shaped by commitments and responsibilities to international bodies and treaties, obligations to its constituents, the need for conservation of stocks, and maintenance of self interest.

Since 1970 most of the tuna research carried out nationally by NMFS has been conducted at the Southwest Fisheries Center (SWFC), with the exception of research on Atlantic billfishes and bluefin tuna which has been conducted at the NMFS Southeast Fisheries Center (SEFC) in Miami, Florida. This year, however, in response to the major social, economic, and political changes which have taken place in the tuna industry, in this country and abroad, there has been a realignment of tuna research responsibilities within the NMFS. Under the leadership of Joseph W. Angelovic, NMFS National Tuna and Billfish Research Coordinator, the SEFC is now responsible, under Richard Berry, for NMFS research to support the International Commission for the Conservation of Atlantic Tunas (ICCAT), while the SWFC, under my direction, is responsible for all NMFS research for the Indian Ocean, western and central Pacific, and any other Federal efforts associated with the eastern tropical Pacific.

Specifically, the SEFC is concerned with species and stocks in the Atlantic Ocean and the Gulf of Mexico: bluefin, yellowfin, and skipjack tunas, albacore, swordfish and marlins, mako shark, and bigeye tuna. For bluefin tuna their responsibilities include estimates of spawning stock size in the Gulf of Mexico, identification of Atlantic stock structure, determination of trans-Atlantic movements; estimation of stock size of juvenile bluefin tuna, establishment and verification of growth rates; provision of abundance estimates and fisheries statistics to ICCAT, and the monitoring of the Japanese catch. For the Atlantic tunas, the job of the SEFC is to provide status of stocks reports and fishery statistics to ICCAT. On research on Atlantic billfish, the SEFC establishes data bases, determines status of stocks, develops management measures for fishery management plans, and

provides fisheries statistics and abundance estimates to ICCAT. Regarding work on mako sharks and bigeye tuna, the SEFC establishes basic biological and fisheries data bases and provides fisheries statistics to ICCAT.

The specific concerns of the SWFC are with the yellowfin and skipjack tunas, billfishes and swordfish, and other oceanic pelagics of the North and South Pacific Ocean, central, western, and southern Pacific and with the Indian Ocean. The research program includes the monitoring of tuna fishery trends in the central and the western Pacific Ocean and the assessment of yield potential to evaluate the impact of changes in effort and fishing technology during rapid development.

Other tuna-related programs include the assessment of the South Pacific albacore populations, analysis of basic fishery statistics on tuna, billfishes, and other important pelagic species of interest to U.S. commercial and recreational fishermen, principally the sport fishery for billfishes, monitoring tuna fishing activity, and preparing catch and effort statistics and economic data on market transactions. Other important activities include the provision of basic fishery analysis and management information on tunas and billfishes to international fisheries bodies and commission, the conduct of studies on the status of dolphins involved in the eastern tropical Pacific tuna purse seine fishery, and research to determine the status of North Pacific albacore.

The future of tuna research in the Federal Government lies, I believe, in the ability to conduct mission-related research to understand better the distribution and abundance of tunas in our areas of interest and to improve our ability to monitor and predict events affecting stock abundance within the fisheries.

IMPORTANT RECENT CHANGES IN THE U.S. TUNA INDUSTRY AND GOVERNMENT POLICIES FROM INDUSTRY'S PERSPECTIVE

August Felando
American Tunaboat Association
San Diego, California 92101-5896

There have been no recent changes on the policy issue of tuna fishing access by the U.S. tuna industry and the U.S. Government.

The American Tunaboat Association (ATA) still has the conviction that the regional license and management approach is correct for the fleet.

The ATA remains supportive of the efforts of the U.S. Government to negotiate regional licensing agreements in the eastern and western Pacific as a step towards regional conservation and management treaties.

The Eastern Pacific Ocean Tuna Fishing Agreement (EPOTFA). Ratification of five countries is required. Costa Rica has not as yet taken final action to ratify EPOTFA.

The agreement on fisheries between Pacific island states and the United States: The ninth round of negotiations is scheduled for mid-July at the Cook Islands.

Provisions of the Compact of Free Association extend the policy relating to tuna fishing access as provided in the Fishermen's Protective Act and the Magnuson Fishery Conservation and Management Act (MFCMA).

There have been no recent changes in Federal legislation adversely impacting the operation of U.S. tuna vessels.

The Fishermen's Protective Act (FPA)

> Lawsuit to seek a declaratory judgment on section 7 with respect to the issue of whether the Fishermen's Fund is to be funded 100% by industry.

Magnuson Fishery Conservation and Management Act

> No changes in the tuna provisions are expected.

Immigration and Nationality Act

> Amendment relating to the right of alien crewmembers on U.S. fishing vessels operating in Guam to go ashore has been adopted by both the Senate and the House.

The 1983 Reagan Proclamation relating to the exclusive economic zone is supportive of the U.S. tuna position as manifested in the MFCMA and the FPA.

The legislative history concerning Senate ratification of the San Jose Treaty reaffirms the tuna policy position of the United States.

The ATA takes the position that Article 64 of the Law of the Sea Convention of 1982 is supportive of the United States tuna position.

The U.S. tuna seiner fleet is experiencing a substantial decline in total capacity and in the number of operational vessels.

Presently over 24% of the fleet (number) is idle.

The fleet is about equally divided operationally between fishing grounds in the eastern Pacific and the western Pacific.

RECENT CHANGES IN TUNA RESEARCH REQUIREMENTS

Robert E. Kearney
Inter-American Tropical Tuna Commission
c/o Scripps Institution of Oceanography
La Jolla, California 92093

The last 10 years have seen many major changes in the world's tuna fisheries. As one of the three major reasons for fisheries research is the response to management's requirements (the other two being (1) the personal interest or motivation of individual researchers and (2) the need to earn a living coupled with the desire for greater financial returns through promotional opportunities), it is not surprising that fisheries research requirements should also have changed. Because of the complexity of individual, institutional, national, regional, and international interest in the many forms (e.g., biological, oceanographical, statistical, economic, social, and political) of fisheries research, it is difficult to generalize. However, the need to consider the tremendous differences among the numerous tuna species and the management of the fisheries which operate on them was stressed as fundamental. The differences in the population dynamics between skipjack and southern bluefin tunas, for example, are greater than those between lobsters or sardines and southern bluefin tuna.

Within the framework of greater diversity among species a few generalities were highlighted:

1. The necessity to adapt the changes in most coastal state attitudes to the Law of the Sea to improve the quality and availability of catch and effort data.

2. The need to appreciate the limitations of all data and the models used in analyzing them. This is more of a problem recently with widespread use of canned computer packages.

3. The need to align research for resource conservation with the population biology of the individual species.

4. The urgency of more fully understanding the total life cycle of tunas and the particular need for more information on early life histories.

5. The need to present scientific results in a format which stresses their importance to fishermen and managers.

6. The need to understand interaction among fisheries and to acknowledge the immense differences among the many types of interactions.

RECENT PROBLEMS IN THE U.S. TUNA INDUSTRY AND AN OUTLOOK

Dennis M. King
ERG Pacific Inc.
1050 Rosencrans Street, Ste. F
San Diego, California 92106

PROBLEMS

It is well known that the U.S. tuna industry and the global tuna industry in general have been shaken up by major shifts in the geographic pattern of tuna fishing, an increase in world tuna supplies, and corresponding price declines in major tuna markets. In this presentation I will outline a few of the events that have taken place in the U.S. tuna market over the past few years which precipitated these dramatic changes and caused some problems for the U.S. tuna industry.

CAUSES

During 1979-82, retail canned tuna prices in the United States increased by 17% (Source: NMFS). This price increase, along with a coincidental decline in general economic conditions and lower prices for tuna substitutes in the U.S. market, resulted in a 15% decline in U.S. per capita tuna consumption from 3.2 lb in 1979 to 2.7 lb in 1982 (Source: NMFS). This market decline led to an overall annual reduction in wholesale and retail canned tuna sales of around 5.75 million standard cases (a standard case = 19.5 lb) which corresponds to a reduction in annual raw tuna requirements for the U.S. market of around 115,000 metric tons (50 standard cases per metric ton).

RESPONSES

While this slump in the U.S. market caused some decrease in U.S. tuna harvesting activity, most U.S. vessels continued to fish. However, since the U.S. market required less raw fish, much of the raw and frozen tuna produced by the U.S. fleet entered the world market or forced tuna caught by other nations on to the world market putting downward pressure on international tuna prices at a time when the international market was already glutted with low-cost tuna from expanding western Pacific and Indian Ocean fisheries and from Mexico. The abundant supply of low cost raw and frozen tuna on the world market at a time when U.S. wholesale and retail canned tuna prices were still relatively high, offered tremendous opportunities for foreign canners to penetrate the U.S. market.

As canners in Thailand and the Philippines increased production and exports to the United States, the growing competition in the U.S. market finally drove down canned tuna prices followed by raw tuna prices. A strong U.S. dollar during this period, however, allowed non-U.S. tuna harvesters and processors to withstand the declines in U.S. tuna prices more easily than U.S. tuna harvesters and processors so U.S. imports continued to grow. The U.S. tuna fishermen and tuna processors were facing steadily increasing

costs while market conditions continued to deteriorate, and during the early 1980's, the entire U.S. tuna industry--harvesters and processors--suffered under a severe cost-price squeeze.

The major costs of owning and operating a tuna purse seiner are more or less fixed; so during this period of low tuna prices, many vessel owners tried to keep revenues above costs by increasing their production of fish. Responding to lower fish prices by increasing fish production, although surprising at first glance, is entirely reasonable from the point of view of an individual fisherman trying to survive; in the aggregate, however, this response put further downward pressure on short-term prices and the market problems worsened.

As time passed and fish prices and vessel profits continued to decline through 1985, the less efficient and the less financially secure vessel owners faced severe financial problems and many lost their boats. Tuna purse seiners, however, have few alternative uses so, as vessels encountered financial problems, many were merely resold at distress prices and returned to the fishery under new management. At the present time, many U.S. vessel owners and their financial supporters are simply absorbing short-term economic losses in the hope of being among the survivors when the international fleet is finally pared down and market conditions improve.

THE OUTLOOK

Although the size of the U.S. fleet is slowly shrinking, its production has been fairly steady while the amount of tuna supplied to the world market by other national fleets continues to increase. In a slack tuna market this puts continuous downward pressure on international tuna prices. Despite some noteworthy developments in Europe and Japan, the United States will remain the only major accessible market for tuna, especially for growing supplies of skipjack tuna, and the demand here will not keep pace with supply increases. Further increases in global tuna landings therefore, are likely to prolong the current slump in ex-vessel prices, and although market conditions will most certainly improve over the long-run, it does not seem that a major upswing will be seen in the near future.

SUMMARY

In the absence of some major change in the organization of global tuna fishing or some new market development, the difficult times are likely to persist for tuna fishermen all over the world. Low tuna prices simply do not drive tuna vessels out of the global fleet fast enough for prices to recover quickly once conditions of oversupply appear. When the United States embargo on Mexican tuna is lifted, there will be another surge in competition for the U.S. market and further downward pressure on U.S. tuna prices and international tuna prices in general. Then things should get really interesting.

LICENSING DISTANT-WATER TUNA FISHING FLEETS: THE EXPERIENCE OF PAPUA NEW GUINEA

David J. Doulman
Pacific Islands Development Program
East-West Center
Honolulu, Hawaii 96848

Papua New Guinea has a Declared Fisheries Zone (DFZ) covering 2.3 million square kilometers of the western Pacific Ocean. The extensive tuna resources found in the DFZ are only lightly exploited by the domestic industry fishing, and as a result the government encourages exploitation of the fishery by distant-water fishing nation fleets. Currently, Papua New Guinea has two access agreements with distant-water fishing nations. However, foreign fishing vessels (FFV's) from other flag states are also licensed under the terms and conditions of these agreements in a nondiscriminatory manner. The paper explains the determination of access fee payments for distant-water fishing fleets and the terms and conditions of access for FFV's required by Papua New Guinea. Receipts for selected years from distant-water fishing operations in the country's DFZ are presented. The paper addresses aspects of Papua New Guinea's administration and surveillance of its distant-water tuna fishery and compliance issues. Regional considerations as they affect Papua New Guinea's licensing of distant-water fleets is briefly reviewed and some concluding comments made as to how Papua New Guinea has fared in licensing distant-water fleets in its DFZ.

STATUS OF YELLOWFIN TUNA FISHERY IN THE GULF OF MEXICO

Guillermo Compean Jimenez
Universidad Autonoma de Nuevo Leon
Mizar 252 Col. Contry
Monterrey, N.L. Mexico

The Mexican yellowfin tuna fishery in the Gulf of Mexico is performed through longlining. Yellowfin tuna, Thunnus albacares, have been captured in the spring and summer since 1981. This fishery has replaced the Japanese fishery that had operated in this zone since 1963.

The fishing zone of the Mexican fleet is mainly located south of the 25° parallel, since fishing is focused towards the capture of yellowfin tuna, which comprised 90% of the catch or 574 t in 1985. The total catch in 1985 was 615 t and was composed of tuna, billfish, and shark. The tuna captured were mainly adult fish of 60 to 100 cm fork length. Most were sexually mature with a gonadosomatic index higher than 30.0 and average weight of 41 kg.

The Mexican fishery is therefore very similar to the Japanese fishery before 1974, when fishing was mainly focused on yellowfin tuna, but differs in that the fishing effort is still rather small and that the fleet is mainly composed of small ships that operate longlines of 300 to 1,000 hooks. In 1985, the effort consisted of 222,600 hooks with 16 ships of 5 to 20 t. The catch per unit of effort has been relatively high and averaged more than 6 fish for every 100 hooks. In 1985 the average was 6.2 fish per 100 hooks.

Thanks to the support and cooperation of the "Instituto Nacional de Pesca," research efforts are now directed toward the analysis of the capture data, the infestation rate with ecto- and endoparasites, and seasonal analysis of the gonadosomatic index. This work is directed at better establishing the structure of the yellowfin tuna population in the Atlantic Ocean.

RECENT DEVELOPMENTS IN TUNA FISHING IN THE INDIAN OCEAN

Richard S. Shomura
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Before 1979, tuna fishing in the Indian Ocean contributed around 166.2 t of commercially important tunas (yellowfin, skipjack, bigeye, bluefin, and albacore) annually, which constituted around 9.5% of the world catch of these species. By 1983 the Indian Ocean proportion had increased to 11.8%, and recent events suggest a further increase in tuna landings due to the development of purse seine fishing in the western Indian Ocean. The Indian Ocean catch before 1979 came from a number of small-scale tuna fisheries of coastal states, e.g., Maldives, Sri Lanka, and Indonesia, and the distant-water tuna longline fisheries of Japan, Taiwan, and Korea. Additionally, subsistence-type tuna fishing existed throughout the region.

In 1979 tuna purse seine fishing trials were conducted in the western Indian Ocean by the Mauritius purse seiner, Lady Sushill. The Japanese purse seiner, Nippon Maru also operated in the Indian Ocean in 1979. Following the early success of the Lady Sushill, a French purse seiner, Ile de Sein, conducted further purse seine trials in the western Indian Ocean in 1981-82. A commercial tuna fishing operation utilizing four French purse seiners began in 1982. The catch in 1982 was 12.4 thousand metric tons. By 1984 the purse seine tuna fleet had increased to 49 vessels (French, Ivorian, Spanish, and Mauritius flag vessels). There were also reports of U.S.S.R. purse seiners operating in the Indian Ocean during this period. The purse seine catch in 1984 for yellowfin, skipjack, and bigeye tunas and albacore was estimated to be 54.3, 53.0, 2.2, and 0.5 thousand metric tons, respectively. Initially, fishing was confined to sets around debris; however, in recent years the number of sets around free swimming schools has increased. Skipjack tuna dominated the catch of the sets around debris, whereas yellowfin tuna was the dominant species from sets around free swimming schools. Recent catch rates showed that sets around debris averaged about 29 t per successful set, and those around free swimming schools averaged about 23 t per successful set.

U.S. EXPLORATORY FISHING FOR ALBACORE IN THE SOUTH PACIFIC

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Based on the results of trolling exploration conducted by two U.S. fishing vessels and results from a research survey by the NOAA ship Townsend Cromwell conducted in conjunction with the fishing vessels, the prospects appear favorable for establishing a U.S. surface albacore fishery in the South Pacific. High catch rates and total catches made by the fishing vessels, coupled with relatively good weather conditions and the infrastructure in Pago Pago, American Samoa, for selling catches and supporting vessel needs, suggest that it is economically feasible for U.S. vessels to operate in the South Pacific.

Examination of the catch results made by the fishing vessels and the Cromwell and oceanographic measurements that were made concurrently with the fishing revealed (1) albacore catches were associated with the Subtropical Convergence (STCZ), (2) fishing success was highest near the northern boundary of the STCZ, (3) nearly all albacore catches were associated with sea-surface temperature (SST) fronts, (4) best catches were made in warmwater intrusions, and (5) catches were made in waters having SST's in the range of 16.5° to 19.0°C, with best catches made by fishing vessels as SST's near 18.3° to 18.6°C.

COHERENT THEORY ON TUNA BEHAVIOR

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From a synthesis of the available literature, a classification of tuna environmental studies is made and presented through some examples. These examples, concerning monofactorial studies (sea-surface temperature, salinity, etc.) or multifactorial works, introduce the fundamental notion of synergy between the different parameters which define tuna environment. Research involving the concept of mathematical distance and aerial radiometry and tuna survey data is detailed. A fundamental distinction is introduced about the presence, the aggregation, and the catchability of tuna schools. In addition, a general hypothesis on tuna behavior, i.e., "if tuna are present in a zone they will be inclined to aggregate close to any anomalies (gradients) of parameters in their environmental sensing field," is introduced. This hypothesis is in line with our knowledge of the ecology and physiology of tuna. From this hypothesis, modeling based on catastrophe theory is proposed.

METHODOLOGICAL CONSIDERATIONS FOR THE ABUNDANCE ESTIMATION OF DOLPHIN POPULATIONS USING OBSERVER DATA

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An important problem in the management of dolphin populations has been the estimation of the population abundance of the different species involved in the tuna fishery. Of all the methods available, line transect sampling perhaps offers the most useful solution to this problem, using data collected from aerial, research vessel, and fishing vessel surveys. However, the assumptions under which the line transect method gives unbiased estimates of density may be violated in several ways. These violations vary between the different platforms used, but are particularly serious when using data collected from tuna vessels. The use of fishing vessel data is appealing because of the relatively low cost of the information and because search effort is consistently high. Observers are placed on board tuna purse seiners as part of a monitoring program that was implemented by the National Marine Fisheries Service in the early seventies. A similar program was established by the Inter-American Tropical Tuna Commission in 1979, including the international fleet in its sampling scheme. The information collected by the observers on marine mammal sightings and the activities of the boats during fishing operations can be used for abundance estimation, if the effect of the violations of the assumptions of the line transect method can be reduced by additional processing of the data. Some work has been done previously in this direction, analyzing the relative importance of the different problems found with observer data and suggesting several possible solutions. Our objective is to develop a more robust method for estimating dolphin population abundance, reducing the effect of the violations of the main assumptions.

The most serious violation is of the assumption that either searching effort is random or schools are randomly distributed in the study area. We reduce this problem by stratifying the data by encounter rate (number of schools detected by nautical mile searched) so that the distribution of schools is close to random in each stratum, or by searching effort so as to have approximately random distribution of effort in each stratum.

The assumption that schools on the trackline are seen with probability one is not seriously violated by the tuna vessels; only very small schools are likely to be missed when the crew is on search effort.

The movement of schools should be slow relative to the speed of the vessel and independent of it. If schools avoid the boat or are attracted by it, estimates of density will be biased. Crews typically sight schools at distances of several nautical miles, before such movement occurs, but sightings made by the observer may be seriously affected. Schools first sighted behind the vessel are excluded from the analysis, since a proportion of these exhibit vessel attraction.

Radial distances and angles to each school detected should be measured without error. Errors in angles are particularly important for the schools that are close to the trackline. To reduce this problem each school is smeared over an area centered on the recorded position of the school.

The size of the school is not always recorded with the same accuracy. When a set is made, the observer can get a closer look at the school and then make a second, improved estimate of the school size. These pairs of estimates may be used to calculate an adjustment factor for those observations with only an initial estimate of the school size.

The entire analysis is made separately for those schools first sighted by the crew and those first sighted by the observer, since the joint distribution of perpendicular distances cannot be reliably modeled. The results from the two separate analyses are added to produce the final abundance estimate.

Of the models for the detection function tested so far, the hazard-rate model has proved most useful. However, more work is required here, and we plan also to test other stratification factors that may be related with dolphin distribution, such as surface-water temperature.

MOVEMENT ANALYSIS OF SKIPJACK TUNA TAGS

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It is widely held among most biologists, fishery economists, and lawyers that all tuna are highly migratory. Analysis of tagging from the South Pacific Commission (SPC) skipjack tuna program indicates that most skipjack tuna move relatively little during their life; 85% of tags were recovered within the exclusive economic zone (EEZ) of the country in which they were tagged. If movements are measured as diffusion rates, the median diffusion rate is between 400 and 800 km^2/day, which means very little movement, a few kilometers per day. The distribution of diffusion rates indicates that some individuals move quite rapidly, while most fish move slowly. Current analysis indicates that a diffusion model with a single diffusion rate is inappropriate for skipjack tuna.

A simple fishery interaction model is described which incorporates four basic elements, movement rate, natural mortality, distance between fisheries, and fishing pressure in the two fisheries. Interaction between artisanal fisheries and commercial fisheries beyond a 200-mile EEZ will be quite small for skipjack tuna given the diffusion rates estimated from the SPC tagging data.

The large EEZ of countries in the western Pacific mean that the skipjack tuna stocks can largely be considered as resident, and that fishing outside of the EEZ for skipjack tuna will have little consequence on the artisanal fisheries inside of the countries EEZ.

GILL VENTILATION AND PERFUSION IN FREE SWIMMING TUNA

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In all vertebrates the ventilation of the respiratory gas exchange surface is matched to the perfusion of the exchanger according to the O_2 contents of respiratory media. In mammals, air and blood hold equal volumes of O_2 so that one volume of air is breathed for every volume of blood that crosses the gas exchange surface. Seawater contains only one-thirtieth the oxygen in air while tuna blood can carry as much O_2 as mammalian blood. Hence, the ratio between ventilation ($\dot{V}_G$) and perfusion ($\dot{Q}_b$) of the gills is expected to be 30. On the other hand, seawater and air hold like volumes of CO_2 so that $\dot{V}_G:\dot{Q}_b$ ratios of 30 represent massive overventilation for CO_2. In spite of this, tuna have the highest blood CO_2 levels of any fish. In order to explain this paradox we measured $\dot{V}_G$, using dye dilution, and $\dot{Q}_b$, using a doppler flowmeter, in free swimming fish. The $\dot{V}_G$ varied with swimming speed and at the lowest speed was around 1.5 L $\cdot$ min^{-1}. The $\dot{V}_G$ quadrupled when swimming speed doubled. The $\dot{Q}_b$ at the lowest swimming speeds was about 0.04 L $\cdot$ min^{-1}. Hence the $\dot{V}_G:\dot{Q}_b$ ratio approached 40 suggesting that much of the water entering the mouth actually bypassed the gills presumably to preserve CO_2 levels in arterial blood. High levels of CO_2 are necessary to "buffer" blood pH changes after severe exercise and to modulate pH changes caused by thermal effects experienced when tuna migrate vertically, within the water column.

ANALYZING TAG RETURNS FROM A LOCALIZED FISHERY HARVESTING A WIDELY DISTRIBUTED, DISPERSIVE FISH POPULATION

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Localized tag experiments on skipjack tuna and other dispersive pelagic species are not ideal in the sense that the fish are not confined to well-defined regions, but rather, they exchange with fish in neighboring regions. This violates an assumption of most analytical models used to estimate population sizes and exploitation rates of fish stocks. I investigated the effect of such violations on population and mortality estimates with a simulation model of a tag experiment in which tagged fish released within the area of a fishery could move diffusively throughout a much larger region.

I subjected the tag return data generated by the simulation model to a traditional analysis in which dispersion out of the fishery was presumed not to occur. I then compared the analytical estimates of stock size and exploitation rate with the "ground truth" of the simulation model. The population in the area of the fishery was overestimated by the analysis. But the exploitation rate was greatly underestimated because the total mortality (the denominator of exploitation rate) was too big, being forced to include dispersive losses as well as loss by death, and because the fishing mortality (the numerator) was too low as a result of the overestimate of stock size.

Taken at face value these results point to the possibility of dangerously complacent stock assessments. This is an unfair conclusion, however, because the "ground truth" in this situation is based on a narrow interpretation of the stock as being only those fish within the confines of the fishing area. An intuitively fairer definition of a fishery stock would be those fish that affect, and are affected by, the fishery. For a dispersive fish we should expect that such an intuitively defined stock of a localized fishery would occupy a region larger than the area of the fishery itself, and that the exploitation rate of that stock should in consequence be less than it would be for a stock defined strictly by the fishing area. Therefore the traditional analysis is in some sense a "fairer" assessment of the situation than is the ground truth.

But what is the "fairest" stock size and exploitation rate? The question cannot be answered without erecting arbitrary signposts much as statisticians choose arbitrary probability cutoffs. Thus for oceanic, dispersive species, the results of this exercise are really pointing to the inadequacy of our concept of a fishery stock and furthermore to the fact that the traditional questions and techniques of resource assessment need to be reevaluated.

FORECASTING ALBACORE CATCHES: SOME PRELIMINARY RESULTS

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We present some preliminary results of a project that is examining if it is possible to use environmental variables to forecast albacore catches in the North Pacific by 1^{o} square and 2 weeks ahead. For our first look at the data, we are using sea-surface temperature (SST) and the east-west and north-south components of the wind as our environmental variables.

We use a technique that empirically estimates optimal transformations of the variables. With a given area, these transformations increase the predictability by five to seven times over that of the raw data. The optimal transformations show that first, it is the environmental conditions before fishing that are most important, not the conditions while fishing. Second, it appears that a level of an individual variable (such as SST) is not as important as the oceanographic process involved.

Finally, we demonstrate that the raw data will not define fishing season, while the transformed data produce very realistic time series, with well-defined fishing seasons.

SATELLITE REMOTE SENSING AND TUNA FISHERIES

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An overview of the present experience in using of satellite remote sensing in tuna research and in tuna harvesting operations was discussed. In addition a review was given of satellite sensors that are planned for the future that will make ocean measurements.

Twenty new oceanic satellite sensors are planned for launch on eight satellites over the next decade. Of this ensemble of sensors, the marine science and operations communities will have access to a major increase in the prime ocean parameters of surface winds, temperatures, waves, color-derived characteristics, circulation, currents, sea ice and ice sheets, and geodetic information.

Presently, ship and buoy sources for surface marine winds, temperature, and waves produce 2 to 5 thousand reports per day globally, and the satellite-derived sea-surface temperatures provide 30 to 70 thousand sea surface retrievals per day. With the planned satellites and sensors, the ensemble of ocean data will increase to 4 to 5 million retrievals per day.

POSSIBLE RELATIONSHIP BETWEEN EL NIÑO AND JAPANESE TUNA LONGLINE FISHING

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It has been reported by the Japanese longline boats that their catches of yellowfin and bigeye tunas were very good throughout the tropical areas of the three oceans with varying magnitude from 1985 to 1986. These phenomena are unique considering a general decreasing trend of longline hook rates for these two species until recent years.

El Niño events occur in the equatorial Pacific every several years and have become known to be a more global phenomenon extending to the western tropical Pacific. As this phenomenon brings about large-scale changes in oceanographic environments, it has been inferred that El Niño might have a significant impact on fishery and population of yellowfin and bigeye tunas that have major distributional areas in the tropics.

In the present interim report, El Niño event was identified for the western tropical Pacific by the changes of depth of surface mixed layer (SML) which was assumed to have close relationship with distribution of tunas. The SML was calculated for the period 1965-83 from bathythermograph observations made mainly by Japanese research and fisheries training boats and was compared to the catches of yellowfin and bigeye tunas taken by the Japanese boats from the equatorial Pacific during 1952 to 1985 (preliminary data for 1985).

Deviation of the SML from average (1965-83) was in a range of +60 m to -60 m. El Niño years reported in the past accord fairly well with the years with minus deviation in the present study. For yellowfin tuna in the western equatorial Pacific, catch by cohort and hook rates by cohort appear to indicate that cohorts that originated in the El Niño years tend to be bigger than those in other years. There seems no appreciable tendency for hook rates in the El Niño years. For bigeye tuna in the eastern equatorial Pacific, hook rates appear to be higher in the El Niño years. However, like the yellowfin tuna case it seems more likely that bigger cohorts tend to originate in the El Niño years.

ARE EL NIÑO CONDITIONS RETURNING TO THE EASTERN TROPICAL PACIFIC?

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In February 1986 the Climate Analysis Center (CAC) of the U.S. National Weather Service issued a statement in its monthly publication which stated:

> "During the past few months, monitoring has shown that for the first time since the major 1982-83 El Niño-Southern Oscillation (ENSO) event the pattern of sea-surface temperature (SST) anomalies in the tropical Pacific is consistent with the incipient stages of an El Niño.... In light of the current trend in the SST anomaly pattern, and in view of the fact that 4 years have elapsed since the beginning of the last El Niño event, it seems prudent to call attention to these conditions in the form of an El Niño Watch, covering the period February-April 1986."

During the past 25 years that the Tuna Commission has been monitoring SST's in the eastern tropical Pacific (ETP) there have been numerous occasions during the austral (Southern Hemisphere) summer that the SST's have become higher than normal. This usually occurs offshore from southern Ecuador to central Peru westward to a line extending south from the Gálápagos Islands. During most years in this offshore region positive SST anomalies <2°C remain unchanged for several months, and then the SST's return toward normal by the end of the austral winter. In some years, however, the positive anomalies increase and expand to the Equator and eastward to the coast of Peru. This takes place either at the beginning of the austral summer, as in 1982, or at the end of the southern summer from February to April, as in 1969, 1972, and 1976. El Niño episodes with varying degrees of intensity occurred in those years.

The ocean warming that developed along the coast of northern Peru during the austral summer of 1985-86 was not well organized or expansive. There had been continuous upwelling of colder-than-normal water along the Equator during the first quarter of 1986 from long. 100° to 160°W as the southeast tradewinds induced good ocean mixing. There have been SST's up to 1°C above normal southeast of the Gálápagos Islands, and apparently the warm water south of the Gálápagos has created good yellowfin tuna fishing recently. This condition occurred early in 1975 also, 1 year before the weak El Niño of 1976. Between long. 160°W and 160°E in the equatorial region the SST's have been up to 2°C above normal in some places for several months. The easterly winds have been much weaker than normal in this region, and upwelling has been minimal. The CAC had expressed particular concern about warming in this region in issuing its El Niño watch statement. As the austral summer of 1985-86 ended, no El Niño had developed in the ETP. There had been no organized and expanding areas of positive SST anomalies, and most areas of the ETP had near-normal SST's. The Southern Oscillation Index had not reflected the rapid (pre-El Niño) rise, and the sea level

remained below normal along the coasts of Ecuador and Peru. In addition, heavy rains in Bolivia and the east side of the Andes Mountains, which have occurred recently, were associated with non-El Niño conditions. Therefore while it was prudent for CAC to issue an El Niño watch, it is clear that an El Niño is not imminent. It is quite likely that large-scale warming in the ETP, which may lead to an El Niño, will not appear until the beginning or end of the 1986-87 austral summer. In May 1986 the CAC called off the El Niño watch.

HORIZONTAL AND VERTICAL MOVEMENT PATTERNS OF FAD-ASSOCIATED YELLOWFIN TUNA

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The vertical and horizontal movements of tuna-associated with fish aggregation devices (FAD's) and island coastline features have been monitored using depth sensitive ultrasonic transmitters. Operating costs have been minimized by adapting tracking technology for use aboard a small vessel. Thirteen yellowfin tuna, Thunnus albacares, and two bigeye tuna, T. obesus, have been tracked. Acquisition of replicate tracks (average duration 40 hours) has allowed behavioral trends to become apparent.

The behavior of yellowfin tuna associated with FAD's is very similar to that exhibited by fish of that species when they are found in association with island coastline topography. That is, the fish are very tightly associated with these features during the day and make excursions away from them at night. The average length of these excursions is 5.3 nmi). Analysis of preferred temperatures of yellowfin tuna indicate that 85% of daylight hours is spent in the mixed layer (45%) and top three degrees of the thermocline. The high incidence of yellowfin tuna along the 75 m (40-fathom) contour in Hawaii may result from the intersection of the thermocline with the island topography. The FAD's thus appear to mimic the influence of coastline topography on the behavior of yellowfin tuna. Implications of these data for FAD deployment strategies are that to be most effective, FAD's should be located at least 5.5 nmi, and preferably over 11 nmi, from the nearest 75 m (40-fathom) contours. Trolling alleys could be created by placing adjacent buoys approximately 10 nmi apart. Subsurface buoys should be as effective as surface buoys for aggregating yellowfin tuna.

CARDIOVASCULAR AND RESPIRATORY RESPONSES OF SKIPJACK AND YELLOWFIN TUNAS EXPOSED TO BRIEF PERIODS OF LOW AMBIENT OXYGEN

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Physical characteristics of the water column are important in modeling distribution, habitat, and gear vulnerability of tuna. The Barkley model utilizes water temperature and oxygen content to predict the size, location, and depth of the skipjack tuna, Katsuwonus pelamis, habitat. Work in the National Marine Fisheries Service (NMFS) Tuna Behavior and Physiology Program has focused in recent years on evaluating the physiological cornerstones of the Barkley model. This talk will concentrate on research being done to refine the model in terms of the tolerance of skipjack tuna as well as yellowfin tuna, Thunnus albacares, to low ambient oxygen (hypoxia).

Previous estimates of low oxygen tolerance in tuna, which are obligate ram-ventilators, were based on death or changes in swimming speed. These methods indicated a response to hypoxia only at levels below 90 mm Hg, and a marked difference in sensitivity between yellowfin and skipjack tunas. The current experiments are designed to more accurately evaluate the animals' response to hypoxia by directly measuring cardiorespiratory changes.

Tunas were anesthetized, instrumented, and positioned in a water stream flowing at a velocity equivalent to a tuna's normal swimming speed (2 bl/s). A spinal injection of lydocaine HCl prevented tail flexion but left the respiratory apparatus undisturbed, thus allowing the fish to control its own ventilation volume. Tuna's were then exposed to brief periods (1-2 minutes) of hypoxia (140-150 mm Hg), presented in a random sequence of 20 mm Hg steps. Measurements were made during a control period immediately prior to hypoxic exposure, during hypoxia after the oxygen tension had stabilized, and immediately following return to normoxia. Physiological parameters measured included: ventilation volume, measured by dye dilution; gape, measured by eye or impedance electrodes glued to the snout; heart rate; and cardiac output, measured with an ultrasonic Doppler flow probe glued to the tissue on the inside of the gill cavity directly over the ventral aorta.

We found tuna to be more sensitive to the partial pressure of oxygen in the surrounding water than previously indicated by tests based on lethality or change in swimming speed. When exposed to mild hypoxia (P_{O2} = 125 mm Hg), compensatory cardiorespiratory adjustments are initiated. The first response is an increase in mouth gape and ventilation volume, which is accompanied by reduction of heart rate (bradycardia) as hypoxia becomes more severe. Cardiac output is maintained by increasing stroke volume until water P_{O2} falls to 95 mm Hg, whereupon cardiac output also begins to

decrease. Skipjack tuna show a stronger bradycardia and a smaller change in gape and ventilation volume than yellowfin tuna. This may be a result of their significantly higher resting heart rate, gape, and ventilation volume.

Recent tracking data collected by Holland et al. indicates that yellowfin tuna tend to limit themselves to shallow depths where the oxygen partial pressure is greater than 125 mm Hg. This is an indication that moderate hypoxia, well above the lower lethal limit, can have an impact on fish distribution. The implications to the Barkley model, which is based on lower lethal oxygen limits, are very important. A future study will measure the actual blood oxygen levels of tuna exposed to hypoxia and will provide the most accurate assessment of the tuna's tolerances to low oxygen. When this information is combined with work to be carried out on effect of temperature on hypoxia tolerance, we will be able to better understand the physiological phenomena underlying habitat selection, natural mortality, and gear vulnerability of yellowfin and skipjack tunas.

OXYGEN-SENSITIVE AFFERENT INFORMATION ARISING FROM THE FIRST GILL ARCH OF YELLOWFIN TUNA

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Environmental hypoxia has been shown to elicit both respiratory and cardiovascular responses, of varying magnitude, in all fish that have been studied to date. Whereas the ventilatory response in teleost fish is strong, consisting of increases in both respiratory frequency and tidal volume, very little response is shown by elasmobranch fish. Although there is some evidence to implicate the pseudobranch of teleost fish as a possible receptor site involved in the ventilatory response, most data implicates putative arterial chemoreceptors, possibly located within the central nervous system.

The cardiac response to environmental hypoxia, in both elasmobranchs and teleosts, consists of an immediate, intense bradycardia accompanied by an increase in cardiac stroke volume. Often, in teleosts, these changes are evenly matched and thus produce little change in cardiac output. In elasmobranchs, the receptors involved in producing this response are diffusely spread throughout the orobranchial and parabranchial cavities and are innervated by cranial nerves V, VII, IX, and X. In teleosts, they are primarily confined to the first gill arch and innervated by cranial nerves IX and X.

Although the general location and innervation of the receptors involved in these cardiac responses have been described in elasmobranchs and teleosts, nothing is known of their exact location or response characteristics.

In the present study, we have recorded afferent impulses from the Xth cranial nerve innervating the first gill arch of the yellowfin tuna, Thunnus albacares, in vitro. The results demonstrated the presence of O_2 sensitive receptors in this arch which increased their discharge in response to decreasing perfusion rate, decreasing perfusion P_{O2} and, in most fibers, to decreasing external P_{O2}. Fibers responding to environmental hypoxia exhibited an exponential increase in discharge to decreasing external P_{O2} with a sensitivity similar to that exhibited by cat carotid body chemoreceptors.

Bursting discharge was prevalent in many of the afferent fibers recorded from in this study. Although several recordings revealed fibers exhibiting frequent, small bursts of activity, most showed substantial bursts of over 50 spikes, the bursts occurring from 10 seconds to 1 minute apart. The normal stimulus modality of most of these fibers does not appear to be low O_2 or mechanical deformation of the gill filaments. Fish gills are known to show a

high degree of intrinsic vasomotion, and thus a variety of stimuli associated with smooth muscle contraction and relaxation, changes in vessel flow, or local changes in blood gas or metabolite concentration remain as possible sources of rhythmic stimuli. Approximately 20% of the bursting fibers recorded from were sensitive to lowered P_{O2} in either the bathing or perfusion fluids. Whether the bursting phenomenon seen in these fibers under normoxic conditions represents a rhythmic change in local perfusion and hence cyclic change in local P_{O2}, also remains speculative.

Although the evidence is indirect, the data suggest that the most likely location of the O_2 sensitive receptors recorded from in this study is in close association with the gill vasculature. To begin with, although all O_2 sensitive receptors (bursting and nonbursting) were sensitive to changes in perfusion flow or perfusion fluid P_{O2}, not all were sensitive to changes in the P_{O2} of the bathing solution if adequate perfusion was maintained. Secondly, the speed of response of these fibers to changes in perfusion flow or P_{O2} was extremely rapid, regardless of levels of P_{O2} of the bathing solution. Their response (when present) to changes in the P_{O2} of the bathing solution, on the other hand, was generally slow. The rapid and dramatic increase in receptor discharge associated with cessation of perfusion or reduction in perfusion fluid P_{O2} further suggests that the metabolic rate of receptor cells or surrounding tissue is high and thus local P_{O2} falls rapidly when perfusion flow decreases. As with the overall sensitivity of these receptors to P_{O2}, these additional characteristics are also similar to those of mammalian carotid body chemoreceptors. Taken together with the phylogenetic evidence indicating that the branchial artery supplying the first gill arch in teleosts gives rise to the carotid artery of mammals, this evidence lends strong support to the hypothesis that the O_2 sensitive chemoreceptors located in the first gill arch of teleosts are homologous to the carotid body chemoreceptors of higher vertebrates.

Speculation aside, this study does demonstrate the presence of O_2 sensitive receptors in the first gill arch of tuna with response characteristics adequate to provide the afferent limb for the cardiac responses shown by this species, and other fishes, to environmental hypoxia.

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A NEW ANALYSIS OF THE TUNA BURN PROBLEM

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Based on detailed amino acid analyses and on previous studies of metabolite changes during online swimming of tuna, a new model of the etiology of burnt muscle is developed. According to this model, O_2 lack to white muscle (developing initially during capture) leads to a metabolic collapse, to a drop in ATP concentration, to a consequent opening of ATP-dependent K^+ channels, with an efflux of K^+, and thus to a collapse of membrane potential. When the membrane potential falls far enough to open voltage-dependent Ca^{++} channels, Ca^{++} influx occurs leading to elevated Ca^{++} concentrations in the cytosol. This process is augmented by simultaneous movement of Ca^{++} from sarcoplasmic reticulum (SR) and from mitochondria into the cytosol, and by Na^+-stimulated Na^+/Ca^{++} exchange. At high intracellular concentrations, Ca^{++} can be devastating. One of its more notable effects involves the activation of Ca^{++}-dependent proteases, which preferentially target key components of the contractile machinery (troponins, tropomyosin, C-protein, M-protein, Z-discs, α-actin) and thus cause disassembly of myofilaments prior to any significant hydrolysis of myosin or actinin. This process is autocatalytic in the sense that Ca^{++}-activated proteases may act upon SR, thus increasing Na^+/Ca^{++} exchange, and ultimately adding more Ca^{++} to the cytosolic pool. According to this model, the differences between burnt and unburnt regions of the myotome is simply due to how far each region has moved along this self-destructive, autocatalytic pathway. The model is helpful in explaining previously perplexing data and in making useful (i.e., measurable) predictions for further studies of this important problem.

SKIPJACK TUNA AS AN ELITE ATHLETE OF THE SEA: INSIGHTS FROM LACTATE METABOLISM

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Tuna are capable of outstanding athletic performances. Not only can they sustain moderate speeds over extremely long distances, but they can also reach very high burst swimming velocities. These unusual capabilities must be supported by adequate metabolic adaptations which should include fast fluxes of fuels to the working muscles during aerobic endurance swimming as well as fast fluxes of anaerobic end products to their sites of catabolism during recovery from burst exercise.

Unfortunately, most of the information presently available regarding exercise and recovery in fish only deals with metabolite concentrations. The measurement of metabolite fluxes is required if we want to understand fuel supply and end product catabolism. Therefore, the goal of this study was to determine lactate and glucose turnover rates in the blood of skipjack tuna. Lactate was chosen because of its recognized key role in the metabolism of exercising animals and also because previous studies had shown that lactate metabolism of tuna is very unusual. One of the peculiarities of tuna metabolism resides in the fact that they are able to clear lactate from their blood six to eight times faster than any other fish during recovery from burst swimming. Glucose was also investigated because it is the other main carbohydrate fuel used by contracting muscles and because lactate can be converted to glucose in the liver as part of the so-called Cori cycle.

Turnover rates were measured by bolus injection of radio-labeled lactate and glucose in catheterized 1-2 kg skipjack tuna. Lactate turnover rates ranged from 112 to 431 μmol/min/kg and were correlated with blood lactate concentration. After correcting for the effects of body mass and temperature, tuna showed higher lactate turnover rates than reported for mammalian species. Glucose turnover rate averaged 15.3 μmol/min/kg in tuna, a value similar to mammalian rates but about 10 times higher than what has been measured in other teleosts including another fast-swimming fish, the coho salmon.

Even the highest lactate turnover rate measured in tuna cannot explain the very short time these animals require to clear lactate from their blood. This strongly suggests that not all lactate accumulated in the white muscle mass of an exhausted tuna passes via the blood during recovery from burst swimming. Indeed, a significant portion of this lactate load has to be metabolized directly in white muscle. In addition, very little labeled lactate was converted to glucose suggesting that the Cori cycle is not an important pathway for lactate metabolism during recovery in tuna.

This study demonstrates some of the most important metabolic adaptations allowing tuna to be such outstanding athletes. It not only improves our understanding of tuna biology per se, but also emphasizes the fact that

scombrids represent an invaluable model for research in exercise physiology and biochemistry.

The study was carried out at the Kewalo Research Facility (Southwest Fisheries Center Honolulu Laboratory), and this paper is based on a recently published artcle. (J.-M. Weber, R. W. Brill, and P. W. Hochachka. 1986. Mammalian metabolite flux rates in a teleost: Lactate and glucose turnover in tuna. Am. J. Physiol. 250:R452-R458.)

STRATEGIES FOR ELEVATING BRAIN AND EYE TEMPERATURES IN TUNAS, SHARKS, AND BILLFISHES

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Many species of large pelagic fishes and sharks are able to maintain warm brain and eye temperatures. Tunas and mackerel sharks are well known for their ability to maintain warm muscle temperatures. In addition, they are also able to maintain brain temperatures up to 14°C above water temperature. Tunas and mackerel sharks have vascular countercurrent heat exchangers located in the circulation to the brain and eye. The presence of the vascular networks in the cerebral circulation allows these fish to conserve heat that is constantly being generated in the aerobic (red) swimming muscles.

Billfishes are also able to selectively warm the brain and eyes, but their muscle and viscera remain at water temperature. Marlins, sailfishes, and spearfishes captured on hook and line have temperatures in the brain and eyes up to 7°C above the ambient water temperature. Other researchers have shown that brain temperature in swordfish can be as much as 14°C above water temperature. The billfishes do not have the high proportion of aerobic muscle fibers in their body musculature and do not maintain the elevated whole body temperatures associated with the warm tunas and mackerel sharks. To warm the brain and eye an unusual heat-generating tissue is present beneath the brain. The heat-producing or thermogenic tissue is a highly modified eye muscle. Only a portion of this eye muscle contains normal skeletal muscle tissue; the rest consists of a novel muscle tissue that is modified for heat generation and not contraction. Both the structure and the biochemistry of this muscle tissue is very different from that of normal skeletal muscle. A large vascular heat exchanger is associated with the thermogenic tissue thus preventing the convective dissipation of the heat at the gills. The thermogenic tissue provides a warm supply of blood to the brain and eye.

Other fishes (opah) and sharks (thresher) have unusual anatomical arrays in the cerebral and orbital circulation that probably serve the function of brain and eye warming. A thermogenic tissue is also present in one scombrid fish, the butterfly mackerel. The independent evolution of brain and eye warming systems in many species of pelagic fishes indicates that there may be some advantage associated with maintaining neural tissues such as the brain and eye above the ambient water temperature.

Given the pelagic nature of all these fishes, it is difficult to obtain experimental data which can address the utility of having warm brains and eyes. The main function of such elaborate physiological mechanisms appears to be related to keeping the central nervous system (the control center of the body) at a constant warm temperature. This should allow the fish to make rapid vertical excursions into cooler waters without any ill effects. In addition it is possible that the warming of the eye in some way enhances

the ability of the fish to detect a visual stimulus. To examine this in more detail, a preliminary study by Block, Brill, and Bushnell (unpublished data) was carried out at the Kewalo Research Facility (Southwest Fisheries Center Honolulu Laboratory) on live skipjack and yellowfin tunas. The study was aimed at determining the effects of rapid temperature changes on a simple measure of the visual response called the electroretinogram (ERG). The ERG's were recorded from tunas by implanting electrodes on the surface of the retina. The results suggest that vision in tuna is sensitive to temperature changes. Thus, warming of the eye may be an advantage for pelagic predators as they migrate vertically through the water column, encountering rapid temperature changes in search of prey.

REVISION OF THE FRIGATE TUNAS, GENUS AUXIS

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For many years the frigate tunas of the genus Auxis were considered to be one worldwide species, Auxis thazard (Lacepède). In 1962, Fitch and Roedel showed that there were two species in the Pacific and used the names A. thazard for the narrow-corseleted frigate tuna and A. rochei (Risso) for the wide-corseleted frigate tuna or bullet tuna. Use of the name A. rochei was based upon the supposition that only one species occurred in the Mediterranean Sea and Atlantic Ocean. Subsequent work demonstrated that two species occur in the Atlantic, reopening the question of the proper name for the bullet tuna. The western Atlantic population of wide-corseleted frigate tuna differs from typical A. rochei in having a narrower corselet (usually 6-9 scales wide under the second dorsal fin compared to 8-19 in the eastern Atlantic and Indo-Pacific) but appears best referred to A. rochei, probably as a separate subspecies. Fitch and Roedel also showed that the eastern Pacific populations of both species differed significantly from the Indo-West Pacific populations. These populations appear differentiated at the subspecies level. The eastern Pacific subspecies of A. thazard has more gill-rakers (usually 43-48 compared to usually 38-42 in the Atlantic and Indo-West Pacific), thus agreeing with A. rochei. The eastern Pacific subspecies of A. rochei has an even wider corselet (usually more than 20 scales wide under the second dorsal fin compared to 8-19 scales in the Indo-West Pacific).

THE STANDARD METABOLIC RATE OF TUNAS: WHY IS IT SO HIGH?

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The standard metabolic rate (SMR) of fishes is the metabolic rate of a postabsorptive animal completely at rest. It therefore represents the energy demands of all metabolic processes (e.g., osmoregulation, pumping the blood) except swimming and digestion. The SMR is an important input parameter to energetics, growth, natural mortality, and population dynamics models.

The SMR is usually determined by extrapolating swimming speed-metabolic rate curves back to zero swimming speed. However, this is not possible in tropical tunas such as skipjack, Katsuwonus pelamis, yellowfin, Thunnus albacares, and kawakawa, Euthynnus affinis, which do not survive well in a swimming tunnel. The SMR of tropical tunas were therefore measured directly. Individuals were paralyzed with a neuromuscular blocking drug (gallamine triethiodide) to stop all overt muscular activity and then placed in a sealed box flow-through respirometer. Measurements were continued until a fish's metabolic rate remained stable for at least 1 hour. When compared to other active teleosts, such as salmon and trout of the same body size, tunas have SMR's roughly four to over six times higher. The high SMR's of tunas are not an artifact of the system used to directly measure SMR because, using the same methodology, rainbow trout, Salmo gairdneri, had SMR's not significantly different from the SMR's estimated by extrapolation of metabolic rate/swimming speed curves back to zero swimming speed. Since SMR is the energy demand of fish completely at rest, hydrodynamic drag considerations are not a factor. Therefore, the main questions addressed are "why do tunas have such high SMR's and what does this mean with respect to natural mortality estimates and stock assessment models?"

I hypothesize that high SMR's of tunas are a direct result of tunas' ability to achieve exceptionally high maximum aerobic metabolic rates (MMR's). The MMR's of tunas are approximately an order of magnitude higher than those of sluggish bottom dwelling species such as flounder and approximately four times higher than those of active teleosts such as salmon and trout. The advantages to tuna of high MMR's include: high sustained cruising speeds which allow large areas of the ocean to be searched for food patches, rapid digestion of food and therefore increased frequency of feeding bouts, quick repayment of oxygen debts (i.e., rapid lactate metabolism), and high rates of somatic and gonadal growth. Tuna have evolved all the anatomical, physiological, and biochemical adaptations necessary to achieve exceptionally high MMR's. These include: large gill surface areas, thin blood-water barrier in the gills, high blood oxygen carrying capacity (i.e., high hematocrit and high hemoglobin levels), high maximum cardiac output, elevated muscle temperatures, high muscle myoglobin levels, high muscle mitochondria density, and high muscle aerobic enzyme activity levels. However, the "cost" to tunas of the ability to achieve exceptionally high MMR's are exceptionally

high SMR's. Large gill surface areas result in high osmoregulatory energy costs even at rest. Data on the SMR's and MMR's of other teleosts support this hypothesis. Sluggish bottom dwelling species such as flatfish have low SMR's and MMR's; very active fishes like tunas have exceptionally high SMR's and MMR's; and active teleosts such as salmon and trout have SMR's and MMR's intermediate between these two extremes.

The fishery implications of this hypothesis is that models of tuna energetics, natural mortality, or population dynamics should not include explicit or implicit assumptions that tuna are evolved for maximally efficient use of energy resources. Clearly they are not. Rather, tuna are adapted for maximum rates of energy throughout. Therefore, tunas are capable of very high rates of growth and reproduction, but they also most likely have very high rates of natural mortality.

NATURAL MORTALITY AND ITS ROLE IN POPULATION ESTIMATION

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INTRODUCTION

Of the various parameters involved in tuna stock assessment, natural mortality (M) is the most difficult parameter to estimate. The sheer numbers of individuals in all stocks, combined with the vast geographical ranges they occupy, make traditional estimation procedures difficult. In addition, from the physiological standpoint, evaluations of the mechanisms that represent natural mortality in tunas, and the times during the lives of individual tunas that the mechanisms may prevail, are hampered for several reasons. For example, the tendency for tunas to hydrate (assimilate water) when under-nourished in order to maintain their hydrodynamic form makes traditional condition factors meaningless. And the fact that dead tunas sink makes necropsies, such as might be conducted on birds or marine mammals, impossible.

This presentation was intended to show how estimated natural mortality enters into population estimation, how natural mortality is estimated, what some of the problems associated with the estimation procedures are, and finally, how variations in natural mortality affect predicted populations size.

M AND ITS ROLE IN POPULATION STUDIES

Natural mortality usually enters into population studies through the use of a class of models generically known as cohort models. Secondarily, the output of these cohort models may be used in other assessments such as yield-per-recruit or spawner-recruit analyses.

The earliest cohort model consisted simply of summing up the catch of each age group in a given cohort and thus finding the minimum number of fish necessary to provide for the fishery. Natural mortality was simply ignored. Later models include a term for M and, given an estimate of M and a catch-at-age vector, essentially solve the catch equation and thus through (usually) an iterative procedure find the instantaneous fishing mortality and population size at each time step.

ESTIMATING M

Natural mortality has been estimated by a variety of methods including tag and release studies, analysis of catch-at-age data, correlation studies involving life history parameters and ecosystems modeling. Tagging studies have not worked well for some tuna species because of low return rates which would indicate unrealistically high values of natural mortality. Estimates based on catch data depend on the positive relationship between fishing effort and total mortality and are somewhat useful. However, concurrent effort and

total mortality data are frequently unavailable or too variable to yield precise estimates. In addition, these procedures assume M to be constant over age. Comparative life history approaches attempt to correlate natural mortality with one of several life history parameters for several species of (usually) closely related fish. The most popular of these correlations has involved M and the parameter k from the von Bertalanffy equation. The physiological basis for this relationship is that the faster a fish grows the sooner it dies and because the parameter k determines the rate at which fish of a particular species reaches its maximum size it is theoretically related to natural mortality. Similar analyses have correlated natural mortality with maximum length and weight, maximum age and age at sexual maturity. These methods are valuable for contrasting M for different species and for estimating M for species where no other method is available but they lack ground truth and, again, provide no information on age-specific M. Ecosystem models are intended to estimate the extent of natural mortality due to predation. For any given species, this approach requires knowledge of what the predator species are, their preference for the species in question and their population sizes which in turn requires the population parameters, including natural mortality for each predator. Most of this information is unavailable for modeling tuna species.

THE SENSITIVITY OF POPULATION SIZE TO M

The sensitivity of the predicted age-specific population size was analyzed by means of several simulations conducted with a cohort model. All simulations employed the reverse solution back to age 1, the age at first recruitment, and not age 0. The cohort model used was developed by MacCall. The catch-at-age data used represented the average age-specific catch from the North Pacific albacore fishery for the period 1965 through 1982 for all three major fisheries, the United States jig fishery and the Japanese baitboat and longline fisheries.

Two classes of simulations were conducted. The first class dealt with M as a constant and the second considered M as an age-specific variable. For the constant M simulations, M was held constant during each simulation but varied between 0.0 and 0.6 (annual basis) among simulations. The variable M simulations employed two differently shaped vectors. The first was proposed by Suda who suggested a constant value of 0.2 for all ages prior to age size and then increasing M by 0.2 annually beginning at age 6. The second is a hypothetical but seemingly realistic vector developed as a part of this study. This vector is called a U-shaped vector because:

1. The M begins as a relatively high value when the fish are 1 (0.3) and decreases during the age 2 period (0.2). During this period the fish are small and presumably subject to heavy predation.

2. For ages 3 through 5, M is held at the relatively low constant value of 0.1 because the fish are larger and less liable to predation but are still juveniles. Also, at this time the fish are subject to heavy fishing mortality which reduces their biomass considerably and, therefore, reduces the likelihood of any type of density dependent M.

3. As the fish enter maturity, M increases to 0.2 at age 6 and 0.3 at ages 7 and 8. Not only are the fish in these age groups converting energy into reproductive materials, they are also undertaking extensive migrations into barren ocean areas. Senility presumably begins to exert some force here as well.

   Note: It is the shape of the vector that is stressed here, not the values. The values were chosen simply because the average value for the vector is 0.2 which allows a comparison between the results using this vector with those using the constant M vector at the published value of 0.2.

Given the catch-at-age and either constant or age-specific M, the final step prior to the simulations themselves is the selection of some type of validation procedure. Such a procedure is necessary because, in conducting a cohort analysis, an estimate of fishing mortality at the oldest age (final F) is used as a seed value to begin the iterative procedure and this value will have an impact on the population size and the value of fishing mortality at each time interval predicted by the model. The validation procedure used for this study consisted of calculating the total mortality (Z) for the most heavily fished age intervals (ages 3 through 7) from the catch curve, averaging them, and then, when conducting a simulation, adjusting the final F until the average Z for the same ages calculated from the model output was equal to the average Z calculated from the data as described immediately above.

RESULTS

Different values of M used in the constant M simulations resulted in substantial differences in the predicted age-specific population sizes (Fig. 1). The M is acting analogously to an interest rate: increasingly higher values are increasingly inflationary.

The most noticeable result of the variable M simulations was that the magnitude of the changes was not as important as at what age the changes occurred. For the simulation based on the vector suggested by Suda, the results indicate that even dramatic increases in M at the older ages had little impact on the population vector when it was compared to the results of the constant (0.2) simulation (Fig. 2). This result was no doubt due to the low numbers of fish caught in those age groups. Substantial differences were predicted by results of simulations with the U-shaped vector (Fig. 3) despite the fact that the average value of M (for all ages) was the same for the constant (0.2) simulation as was not the case with Suda's vector in which the average M was 0.35.

CONCLUSIONS

By using a combination of methods a reasonable value of natural mortality can probably be obtained for most stocks of tuna. However, this value will only serve as an estimate assumed to be constant over the life of the fish. Because natural mortality undoubtedly changes with size or age, the subject of age-specific natural mortality should be investigated.

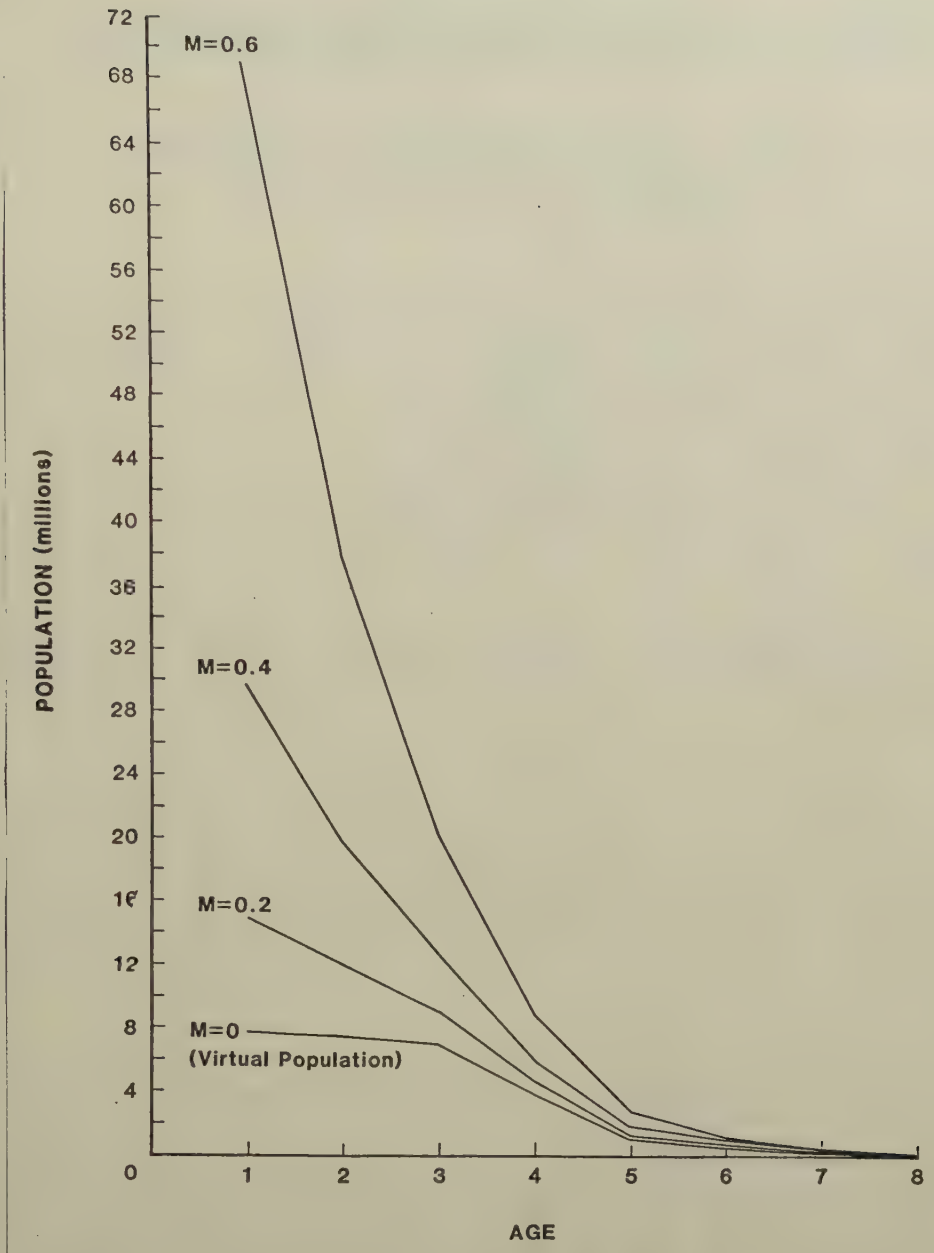

Figure 1.--Predicted population sizes resulting from four different simulations each with a different value of natural mortality (M). Values ranged from 0.0 to 0.6.

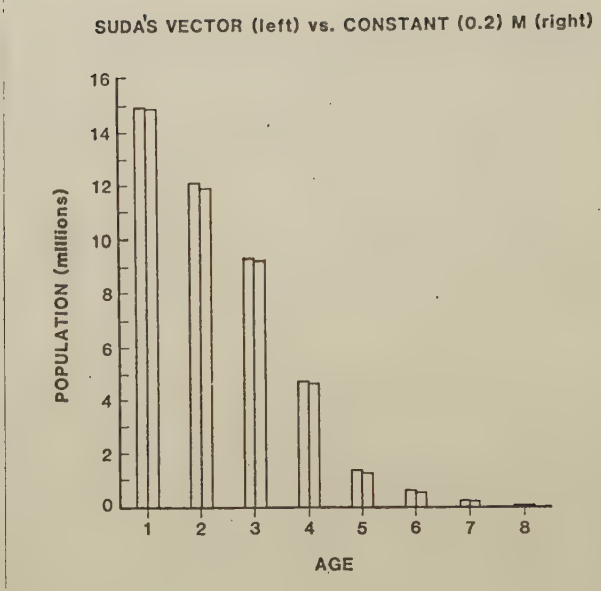

Figure 2.--A comparison of predicted population sizes resulting from a variable natural mortality vector proposed by Suda and a natural mortality vector held constant at the published value of 0.2.

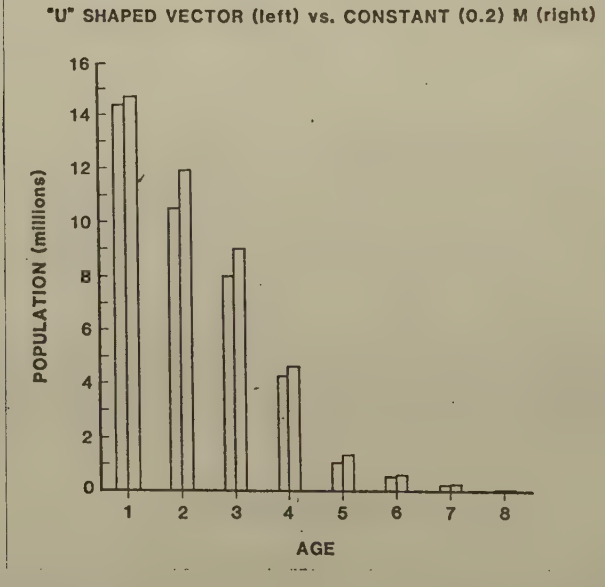

Figure 3.--A comparison of predicted population sizes resulting from a variable natural mortality vector proposed by the author and a natural mortality vector with the same mean value, that of the published value of 0.2.

LIFE AND DEATH ON THE HIGH SEAS: REFLECTIONS ON CONNECTIONS BETWEEN NATURAL MORTALITY AND PHYSIOLOGICAL CONDITION

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The natural mortality rate (M) of fish stocks or populations is extremely difficult to measure accurately, yet this rate is required almost universally as a scalar or vector parameter in mathematical models of fish stock dynamics. Three methods have been used to date to estimate M; 1) analysis of catch-at-age or catch-at-length curves, 2) correlation with life-history parameters, and 3) by summing predicted fluxes to predators. Catch-curve analysis remains at the heart of all three methods; none of them have proved very effective. This is because catch curves are plagued almost universally by biases related to migration, susceptibility, vulnerability, and standardization of effort. Correlations with life-history parameters are remarkably imprecise for single species. The predation-summation method requires numerous simplifying assumptions and massive data sets.

Physiological indexing of mortality risk offers, under certain circumstances, an alternative method to supplement existing analyses. Combining laboratory experiments to identify potentially lethal parameters and the levels associated with risk, with field surveys of the distribution and levels of the same parameters in exploited stocks, can provide a relative measure of risk. The field levels can be translated, via the information gained in laboratory experiments, to relative risk vectors for simulated stocks in fishery models.

CONDITION AND PERFORMANCE: FACTORS AFFECTING SUSCEPTIBILITY OF TUNA TO PREDATION

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Extreme mobility and consequent rapid metabolism, permitting fast growth and prolific reproduction when sufficient energy is located, are characteristic of a life-history strategy designed to exploit high-quality food resources that fluctuate in time and vary in distribution. If tuna gamble large payments in energy against the chances of locating widely distributed and short-lived oases of forage they would be able to take advantage of changing conditions within the vast pelagic ecosystem. The liability of this strategy may be a high rate of natural mortality. A safety feature would be to conserve some energy as fat reserves. Mobility, metabolic rate, and fat storage all vary among the tuna species, but evidence suggests that those species such as skipjack tuna, Katsuwonus pelamis, that reserve very little energy and grow and reproduce rapidly have a high rate of natural mortality; whereas those that grow more slowly, achieve maturity later in life, and reserve larger amounts of energy such as yellowfin tuna, Thunnus albacares, or albacore, T. alalunga, have a lower rate of natural mortality.

Examination of the energy storage "safety feature" in natural tuna populations could provide an indicator of the degree of risk of natural mortality among different subgroups (ages, areas, seasons) within that population. Experiments measuring energy expenditures in small tropical skipjack and yellowfin tunas showed that up to a month was required before starvation led to death at the slow volitional speeds maintained in captivity, but studies of the energetic cost of swimming showed that death due to starvation may be very rapid if speeds are high, even when some food is available. Tuna may become less effective predators and more vulnerable as prey after losing smaller amounts of energy if this loss affects their swimming abilities. Experiments were designed to test this hypothesis by starving tuna for short periods and measuring their swimming speeds (performance) after periods of standardized enforced excercise. Measurements and samples of tissues that might reflect the status of energy stores within the tunas (condition factor, water and lipid content, organ weights, sections for histology, etc.) were collected. The continuing objective of this study is to find some factor measurably related to performance that is resistant to the common techniques used in handling commercial catches so that population sampling may be carried out at processing facilities.

Small (30-38 cm fork length (FL)) yellowfin tuna that adapted to captivity by learning to feed actively were tested regularly for average and minimum sustained speed in performance trials. The tuna were chased with a pole for 30 min by splashing the water behind the fish every 3 sec and by tapping the fork of the tail every 30 sec. After 30 min the fish were chased by thrashing the water behind the fish continuously for 2 min. All movement was videotaped and swimming speeds during complete laps around the circular tanks were measured. Initially two well-fed yellowfin tuna (fasted overnight before trial) were compared with a yellowfin tuna that was starved for 8 days. The well-fed fish sustained swimming speeds above 300 cm/sec initially, and after 25 min they

still sustained speeds above 140 cm/sec, whereas the fish starved for 8 days initially could sustain speeds of only 60 cm/sec, and after 25 min it swam at about 50 cm/sec. Experiments with skipjack tuna had shown that about a week of starvation caused water content (inversely related to energy content) to rise above the range observed in the field. Subsequent experiments were designed to observe performance in tuna within the range of conditions observed in the field. Thus yellowfin tuna were starved for 3 to 5 days for the tests compared below:

Comparisons between speed (cm/sec) and factor levels in 3- to 5-day, starved and well-fed yellowfin tuna (fasted overnight).

	Well-fed		Starved			
	Mean	N	Mean	N	Dif	P
Speed measurement						
Mean 25-30 min	153	7	138	5	11%	NS
Minimum 25-30 min	140	7	117	5	20%	**
Mean 30-32 min	198	4	183	5	8%	NS
Minimum 30-32 min	175	4	139	5	27%	**
Minimum 30-30.5 min	179	7	154	5	16%	*
Factor						
Water content	74.9%	7	76.2%	5	1.8%	*
Dry c-m extract	7.9%	6	7.5%	5	5.1%	NS
Condition factor	1.80	7	1.78	5	1.3%	NS
Width/length	1.52	7	1.46	5	4.3%	NS
10^4 · heart/length^3	0.37	7	0.33	5	11.0%	*
10^4 · liver/length^3	1.63	7	1.32	5	23.5%	*
Fork length (cm)	33.2	7	30.9	5	7.4%	NS

Minimum sustained (for one lap) speeds were most affected by the starvation treatment. Additional factors are being analyzed, particularly alternative methods to assay lipid content. The method of soxhlet extraction of dry tissue with chloroform-methanol (dry c-m extract) is unsatisfactory with samples containing so little lipid. The hepatosomatic index (10,000 · liver wet mass (g)/fork length (cm) cubed) was the most consistent predictor of swimming performance. This is not an ideal factor for sampling at processing facilities, but the results confirm the principle that the distribution of one or several factor levels in the catch will reflect the frequency of fish with reduced abilities that should be more vulnerable to predation.

The factor distribtion can indicate both risk (through the proximity of the distribution to dangerous levels) and the extent to which selective predation on weaker individuals has exploited that risk (by the degree of truncation or skewness in the distribution). Thus we do not have to assume that predator-prey ratio, predator energy requirements, or prey preference are constant, or that the predation rate depends on prey vulnerabilty. By reflecting both the physiological risk and the extent of predation, the distribution of factor levels in the population could provide a realistic physiological index of natural mortality for use in population models.

EFFECT OF A CESTODE (TAPEWORM) PLEUROCERCOID PARASITE INFESTING THE DORSAL AORTA OF THE YELLOWFIN TUNA, THUNNUS ALBACARES

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A parasite, found infesting the dorsal aorta of yellowfin tuna, Thunnus albacares, has been tentatively identified as Dasyrhynchus talismani. This typanorhynch cestode is found as a pleurocercoid larvae which is long (1.5-3 mm), thin (50-200 mm), and tightly folded or coiled within the dorsal aorta from the junction of the first branchial artery posterior to the point where the dorsal aorta enters the first haemal arch. In heavy infestations the parasites cause the dorsal aorta to increase in diameters by as much as five times. Host immune response tissues appear to cement the parasites into a firm pluglike mass and affix it to the wall of the vessel. In this situation, the parasites appear to almost completely occlude the dorsal aorta. In vitro experiments show that the pressure required to push a given flow rate through the dorsal aorta of parasitized fish is extremely high when compared to nonparasitized fish. The parasite, therefore seemed to pose a serious threat to the health of the tuna and this study was undertaken to document the effects of the parasite on the tuna.

Ventricular heart weight was measured as an indication of cardiac hypertrophy (due to increased pumping pressure) and liver weight as a measure of starvation. Length and weight were measured to obtain relative condition factor of the tuna. Otoliths were weighed and compared to length and weight to estimate the size at age of the tuna (i.e., long-term growth rate). The RNA:DNA ratio of muscle was examined to estimate the recent growth rate. A stressed swim test was done to estimate the ability of the fish to burst swim after 30 min of severe exercise. None of the above measurements showed any significant difference between parasitized and non-parasitized tuna, which suggests that infestation has no measurable effect on the physiological functions or the swimming abilities of the fish.

The prevalence of dorsal aorta infestion changes with the size and with season. We found the prevalence rate to be about 50% in fish <30 cm fork length, but only 5% in fish >150 cm. We also found a dramatic drop in infestation during August and September 1985. Previous to this time, dorsal aorta infestation rates in small yellowfin tuna were approximately 50%. During August and September 1985 infestation rates dropped suddenly to about 10%. We believe this was due to an influx of a large separate group of small yellowfin tuna into the Hawaiian fishery. Because of its high prevalence rate and relatively long life of this parasite, it may serve as a useful biological tag.

GROWTH OF YELLOWFIN TUNA, THUNNUS ALBACARES, IN THE EASTERN PACIFIC OCEAN BASED ON OTOLITH INCREMENTS

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The growth of yellowfin tuna in the eastern Pacific is described in terms of several measurements taken from the fish and their otoliths (sagittae). Equations are also developed to predict age from the readily available dimensions of fork length and predorsal length. The data for all of these relationships were obtained from a sample of 196 fish collected during 1977 through 1979 from purse seiners fishing north of the Equator and east of long. 137°W. The fork length range of the sample was 30-170 cm.

The number of increments on a sagittae of each fish was used as a direct estimate of its age in days. The correspondence between increments and days has been validated by tetracycline injection experiments for yellowfin tuna in the length range of 40-134 cm. Circumstantial evidence indicates that the relationship also applies in the intervals of 0-40 cm and 134-170 cm. This circumstantial evidence was derived from: 1) literature on validated increments during early growth for other species, 2) knowledge that structure assumed to be daily increments on yellowfin tuna otoliths have subsequently been validated in the corresponding zone on bluefin tuna otoliths, and 3) a comparison of the growth curve based on increments to others obtained from length-frequency modal analysis. Based on this information the age estimates over the entire size range of sampled fish is believed to be accurate.

In addition to the general growth and age-predictive relationships, the major conclusions of the study are that:

1: Sexually dimorphic growth exists in terms of fork length, fish weight, and the length of the otolith counting path for the entire data set. Examination of the data for 1977 and 1979 also revealed that the fork-length growth of each sex differed within years.

2. For combined sexes there were significant differences among the fork-length growth curves for yellowfin tuna sampled in different years.

3. Yellowfin tuna caught inshore (within 275 miles of the coast) were heavier than those caught offshore for fork lengths between 30 and 110 cm. The situation was reversed for lengths >110 cm.

4. Back-calculated spawning months were distributed uniformly throughout the year in 1974 and 1977, but in 1975-76 and 1978 spawning activity was apparently concentrated in the latter half of the year.

GEOGRAPHIC VARIATION OF REPRODUCTIVE CHARACTERISTICS IN BLACK SKIPJACK TUNA, EUTHYNNUS LINEATUS

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The black skipjack tuna is an epipelagic neritic as well as oceanic species of tuna distributed throughout the tropical and subtropical waters of the eastern Pacific. Specimens were obtained from commercial landings during 1980-82 throughout the eastern Pacific. Four geographical areas were considered separately as study areas, in order to evaluate the extent of geographical variation with respect to those life history characteristics pertaining to reproduction. The boundaries of the strata were chosen to produce the smallest areas in which monthly samples were available throughout the year. Also differences in oceanographic features on a latitudinal basis were considered in defining these strata. The four reproductive characteristics considered are: 1) spawning area and season, 2) size at maturity, 3) batch fecundity, and 4) spawning frequency.

The locations and times of spawning were determined from ova diameter measurements. Spawning occurred during August through October in area 1 around the Revillagigedo Islands (lat. 10°-20°N, long. 105°-120°W), during October through June in area 2 off Central America (lat. 5°-10°N, long. 80°-95°W), during November through March in area 3 in the Gulf of Panama (lat. 7°-9°N, long. 78°-80°W), and essentially no evidence of spawning was observed in area 4 off Colombia and Ecuador (lat. 5°S-5°N, long. 80°-90°W).

The relationship between fork length and the proportion of mature fish estimated from ovarian development was best approximated by a modification of the Richards function. The fork length at which 50% of the females were mature as interpolated from the Richards equations, using the derived parameter estimates was 494.8 mm for area 1, 470.3 mm for area 2, and 457.4 mm for area 3. A method independent from that of the Richards function was used to evaluate whether there are geographical differences in the length at maturity. Nonoverlap of the lower and upper 95% confidence intervals of these estimators is evidence of significantly different lengths at 50% maturity for fish from these three areas.

Spawning batch fecundity estimates were based on counts of hydrated oocytes in three weighed subsamples from either the left or right ovary. The simple linear model was selected as the best function to express the relationships of batch fecundity versus body weight for black skipjack tuna from areas 1, 2, and 3. In order to compare these relationships ANCOVA was used to test for differences in regression parametes among the three areas. The ANCOVA indicated a significant difference in the slopes of the regression lines. The Newman-Keuls multiple range test indicated different slopes in the lines of areas 1 and 3. Further analysis of the regression elevations indicated that none of these three lines are coincidental. The

batch fecundity is highest in the northern area 1 (144 eggs/g body weight), and declines to 77 eggs/g body weight in area 3.

Estimates of the spawning frequency were based on the hydrated oocyte method. In area 1 over a 3-month spawning season an average of 46.8% of the females were spawning per day indicating that the average interval between spawning a new batch of eggs was 2.1 days. In area 2 over a 9-month spawning season an average of 17.6% of the females sampled were spawning per day indicating that the average interval between spawning a new batch of eggs was 5.7 days. In area 3 during the late 1980 to 1982 spawning season an average of 27.8% of the females sampled had hydrated oocytes indicating that the average interval between spawning a new batch of eggs was 3.6 days.

The higher fecundity and spawning frequency in the northern area 1 apparently compensates for the shorter duration of the spawning season and the larger size at maturity.

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